A MEDICAL REVIEW OF THE PHYSIOLOGICAL EFFECTS OF CONDUCTED ENERGY DEVICES (CED)

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Forward

This report is a comprehensive review of the medical and physiological effects of conducted energy devices (CED's). Information for this report was collected from multiple sources. The primary source of material is from the peer reviewed medical literature obtained from PubMed, a comprehensive medical literature search engine. Additional sources include lay press reports and stories, manufacturer provided information, and public government documents.

It is important to realize that the majority of reports and studies regarding CED's have been produced *ex post facto.* The devices as currently used were approved by the U.S. Product Safety Commission based on theoretical calculations. Only now are research groups performing experimental trials on the devices as deployed in animal and human subjects.

Throughout this report we use the term conducted energy device (CED) whenever referring to the larger group of weapons that utilize electricity in order to gain compliance from the subject on whom it is used. We use the word Taser when referring to the devices manufactured by Taser International, Inc.

This report begins with a brief review of the history of CED's. It is followed by background information on the current types of devices in use, most importantly the Taser X-26®. Manufacturer specific information on the X-26 is provided. The concept of excited delirium, which is important when reviewing the safety of any of these devices, is introduced.

The report then reviews animal studies performed using these devices. Following are the human case reports and case series. Lastly in this group are the more recent prospective human studies.

The last section of the report summarizes the specific effects of the device on the various human organ systems by bringing together information from the animal and human studies, as well as the practical experiences of the authors. Three specific conditions are addressed as best as the evidence allows, realizing that in the case of pregnancy and children, ethics simply do not allow prospective clinical studies: cardiac defibrillators and pacemakers, pregnancy, and children.

Finally, after the review of all the relevant information, the report makes several suggestions for the practical management of the subject who has received a CED activation, with a special emphasis on safety when it comes to conditions that are particularly high risk.

Executive Summary

For the professional with limited time, we have included a brief summary of the main findings of the report, with conclusions regarding the effects of the device, where such conclusions can be drawn. For further detail the reader is encouraged to refer to the main body of the document.

- CEDS are often used in situations where a subject is under the influence of drugs, or in a state of excited delirium. These subjects require particular care in their evaluation and treatment after use of the device.

- Excited delirium is a physiologic condition characterized by abnormal body function, which may include elevated temperature, altered pain sensation, or hallucinations. This condition has been associated with Sudden Death in Custody. These subjects are at an increased risk of death by virtue of exhibiting this condition.

- There are 2 main types of CEDs- contact CEDs and projectile CEDs. The most common device currently in use in the U.S. is the Taser X-26®.

- The effects of CEDs vary depending on the type of device being used, organ system in question, placement and distance between the probes on the subject's body, as well as the physical condition of the subject.

- Published research on the health effects and safety of CEDs on humans is limited.

- CEDs do not appear to have any permanent effects on the muscular system other than an increased risk for strains and the potential for causing muscle breakdown with repeated, sustained use.

- CEDs can cause minor injuries to the skin such as punctures and minor localized burns.

- CEDs appear to have the potential for causing bone fractures in those subjects with underlying osteoporosis. They can also cause injuries if the subject falls.

- The effect of CEDs on the brain and central nervous system are unknown. There have not been any reported adverse effects.

- CEDs do not appear to cause cardiac rhythm problems, though data are limited. There appears to be the potential for negative consequences on cardiac pacemakers and internal defibrillators.

- There does not appear to be a negative effect of CEDs on human respiration.

- The effect of CEDs on the pregnant subject is unknown. We suggest a conservative approach to the evaluation of any subject on whom the device is used and is found to be pregnant.

- There is simply not enough data regarding the specifics of the effects of CEDs on children and the elderly.

- Overall, CEDs appear to have a favorable safety profile when compared with lethal force.

- We feel that the following subjects on whom a CED has been used warrant special attention and medical evaluation: 1) Those under the influence or suspected to be under the influence of stimulant drugs, 2) Those in a state of excited delirium, 3) Those with an implantable cardiac pacemaker or internal defibrillator, 4) Pregnant subjects, 5) The very young or very old.

Summary and Description of CEDs and Their Use

CED History

Conducted Energy Devices (CEDs) were originally created for airline personnel to use in thwarting hijacking attempts in the 1970s. The technology was rapidly adopted by law enforcement. The earliest CEDs required officers to make close contact with a subject when discharging the device and were only effective in gaining compliance by inflicting pain. Subsequent modifications led to current models that utilize projectile barbs attached to wires, affording greater safety by providing the ability to mitigate threat from a distance.

CEDs are also known as conducted energy weapons (CEWs), neuromuscular incapacitation devices (NMIDs or NIDs), human electromuscular incapacitation (HEMI) devices, and electronic control devices (ECDs), All refer to the class of less lethal weapons designed to deliver an electrical current to a subject in order to subdue and incapacitate them. In this report we use the term CED when referring to these devices, realizing that all the terms are considered acceptable within the scientific community.

The most commercially successful CED in law enforcement is the Taser, an acronym that stands for Thomas A. Swift's Electronic Rifle. However, other CEDs are currently available on the commercial market for both professional use and general public (Stinger®, Sticky Shocker®, Nova Shock Stun Belt®). According to the manufacturer of the Taser® devices, CEDs have been activated on over 100,000 volunteers during training sessions without complications as well as been deployed by police on over 150,000 subjects during actual confrontations.[1, 2] .The total real number of CED deployments and activations is unknown.

CED types

CEDs typically fall into one of two broad categories - contact CEDs or projectile CEDs. Contact CEDs such as handheld stun guns arc energy across two metal probes and transmit that energy to a subject when the device probes are held in contact with that subject. The use of this type of device requires that the person using the stun gun maintain close enough physical proximity to the subject to directly apply the device and make contact with the subject. Pain is the primary endpoint, as this device does not have sufficient distance between probes to actually incapacitate an individual through an electrical effect on the muscles. Thus, the device can be overcome by those who are highly motivated or under the influence of mind or perception-altering substances.

Other non-projectile electric stun devices include the electric shield and electronic control belts. Electric shields transmit electricity across metal conducting plates on a plexi-glass shield. These devices operate much as a hand-held stun gun in that the shield is pressed against a subject to make contact and a trigger allows the actual activation of energy. While the shields cause a noxious, painful stimulus when held in direct contact with the subject, it may also induce muscular tetany, as the contact points are spread far enough apart to induce muscle contraction. Their effectiveness is based on the contact of the shield with the subject. The energies of these devices vary from 40,000 to 75,000 volts with a stun pulse rate of 17 to 22 pulses per second and a current of 3 to 6 milliamps, which is similar to those of handheld stun guns.

An electronic control belt's primary use is to maintain control of high-risk prisoners already in-custody, during transport or in non-locked facilities such as courtrooms. The device is placed around the waist of a subject and can be remotely activated from as far away as 150 to 200 feet. Once activated the devices discharge for 8 seconds and incapacitates by conducting energy across contact points that are separated sufficiently to induce tetany in large muscle groups during the discharge. The energies of these devices are 50,000 volts with a stun pulse rate of 17 to 22 pulses per second and a current of 3 to 6 milliamps.

Projectile CEDs are those that utilize a firing mechanism to shoot 2 to 4 barbs connected with thin copper wire toward the subject at a distance of up to 21 to 31 feet. An electric current is transmitted from the device to the barbs, arcing across the subject's muscle groups causing incapacitating muscular tetany. The most recent CED that has been developed by Taser International® is the Taser X26. The X26 is a handheld device resembling a handgun that is intended to be used on subjects up to 21 feet away. Per Taser International®, the X26 weighs approximately eighteen ounces and is powered by either NiCad batteries or high output alkaline batteries. The energy output of the device is 5 watts, with 0.36 joules per pulse, 2.1 milliamps and 50,000 volts. It uses an automatic timing mechanism to apply the electric charge for five seconds. When the trigger is depressed, a compressed nitrogen cartridge (1800 lb/in2) fires two probes at an initial velocity of 180 feet per second. The Taser delivers its electrical discharge energy through a sequence of dampened sine-wave current pulses each lasting about 100 microseconds. This energy is neither pure AC nor pure DC, but probably akin to rapid fire, low amplitude DC shocks. The device allows data retrieval (time and date of every trigger pull) for later review, and newer units have an optional module for video and audio recording.

The Stinger® hand-held projectile stun gun manufactured by Stinger Systems resembles a hand gun and fires two or four darts at targets up to 31 feet away. Per Stinger Systems, the Stinger® weighs 18.5 ounces and is powered by Lithium ion batteries. The spark energy is 7 watts in one second, with 20-22 pulses per second, and has a 56 milliamps whole pulse with 7000 volts under a one-ohm load. It utilizes an automatic pulse current when contact is made with the subject as well as manual operation with a 4 second shutoff.

Background on Excited Delirium and Sudden Death in Custody

One issue that surrounds the use of CEDs is the sudden unexpected deaths of subjects in proximity to CED use. Similar types of unexpected deaths have been described in the medical and law enforcement literature following police intervention even prior to the widespread use of CEDs. In fact, the Sudden Death in Custody (SDIC) syndrome has been well described in the medical and law enforcement literature for quite some time.

The actual cause of death in an SDIC case can at times be controversial and has led to numerous lawsuits because of the potential role of law enforcement in the case. Some may claim that specific police actions such as the type of restraint, restraint methods including weight force applied on the individual, and pepper spray use caused the death of an individual.[3-13] However, there is often little evidence to support such attribution in these cases because the deaths appear similar regardless of what police action occurs (that is, SDIC cases have occurred with and without restraint, and with and without pepper spray exposure).

The common link in these SDIC cases appears to relate more to the physiologic state of the individual at the time of the police intervention, rather than the specific interventions performed by the police. In reviewing the literature and individual case reports and autopsies, it appears that most of these subjects are suffering from what has now been termed excited delirium. This is a physiologic state beyond simple drug intoxication. The individual may be hallucinating with an altered sensorium and lower pain perception threshold with evidence of "remarkable strength" as a result. There is evidence of abnormal body function (autonomic dysregulation), with a markedly elevated heart rate and body temperature (resulting in excessive sweating). As a result, individuals appear psychotic and out of control, with little disregard for their or others personal safety. For example, they are often destructive, breaking or running through glass or other objects. Factors that predispose to the development of the excited delirium syndrome including acute on chronic drug use, as well as untreated underlying psychiatric disorders, particularly schizophrenia or bipolar mania.

Because of the clinical state of these individuals, police are commonly called to intervene. This state of excited delirium is associated with an increased risk of sudden death, regardless what modality is utilized to gain control of these individuals. A review by Stratton found an 11% death rate in individuals presenting with symptoms of excited delirium to EMS providers.[5]

Previously, the concept of positional asphyxia from placing a subject in a prone maximal restraint (hogtie) position was implicated in causing deaths to subjects while in custody.[14-16] However, the concept was debunked by physiologic evidence that people do not asphyxiate when left in a prone maximal restraint position. Additional work has further shown this not to be the case, even when combined with exposure to oleoresin capsicum (OC) spray, commonly referred to as "pepper spray", or additional weight force transiently placed on the backs of individuals during the restraining process.[17-25]

Review of the Literature: Animal Studies

This section is a review of each CED related study published utilizing an animal model. These studies used either dogs or pigs as the research model. Though these studies offer interesting insight in to how the devices may affect the physiology of the species in question, it is important to understand the limitations associated with an animal model. No two species are the same, and what may be an effect in one does not always translate to the other. Additionally, these experiments are done using laboratory conditions, including anesthesia, and often with repeated shocks delivered to a single animal. Some of the studies do allow for a rest period between shocks, but the effects of the rest period is not known.

On the positive side, animal studies do allow for the use of some conditions that simply would not be allowed under the study ethics of modern human subjects. Much of the work in research in to cardiac arrest has been done in guinea pigs, rats, pigs, and dogs. The below mentioned study that infused adrenalin in to a pig model to look at the effects of stress would not be allowed in humans. Additionally, we will not ever see studies in humans that seek to find the location of CED dart that is able to produce ventricular fibrillation (VF) with reliability. Therefore, there continues to be a place for these studies, and as we learn more about the effects of these devices, potential areas for research in humans can be elucidated.

Roy and Podgorski performed a study that used an older model stun gun that produced high voltages (>100,000 volts) and short duration pulses (<20 microseconds).[26] They used five different models of stun guns with varying energies. The average value of the current applied during each shock was calculated to be 3.8 mA, higher than the current value for the Taser X26. When towels were placed between the skin and the electrodes to simulate clothing, the maximum current spike was 190 mA with a pulse length of 20 microseconds. Using two anesthetized normal healthy pigs the investigators were able to induce VF when the leads of the stun gun were applied directly to the heart or to the chest of one of the animals in which a cardiac pacemaker was implanted. They surmise that the mechanism of action in that case was not to inhibit the pacemaker, but rather to allow the current direct access to the heart via the pacemaker leads where it induced ventricular fibrillation. The shock also produced cardiac standstill when applied through the layers of simulated clothing for a prolonged period. However, these findings occurred with the 2 stun gun models delivering the highest energy. There were no cardiac effects seen with the lower energy units. This study demonstrated that VF was indeed a possibility, but only at very high energy outputs and when the electrical discharge occurred directly over or had direct access to the heart. Other studies have confirmed this.[26]

McDaniels and Stratbucker studied the advanced Taser M26® in five anesthetized dogs with an average weight of 54 pounds. Electrical discharge of the devices placed directly over the chest failed to induce VF. In 236 discharges, there were no recorded episodes of VF. The authors do note that when both probes were placed directly over the heart they were able to pace the heart similar in action to a pacemaker, but again did not induce VF. [27]

In a study by McDaniel et al, the cardiac safety of the devices was tested on nine pigs weighing 60 kg +/-28 kg. The animals were shocked using a device that was developed to deliver an electrical discharge identical in waveform and charge to that of the commercially available Taser X26® device. The voltage used for this study was less than the 50,000 volts used in the device, however. The animals were shocked for five seconds. The electrodes were placed across the thorax of the animals using the barbs that matched the probes used by the standard device. The study used gradually increasing amounts of charge delivered to identify two levels. The first being the lowest amount of charge required to induce VF at least once - the VF threshold. The second level defined was the highest discharge that could be applied five times *without* inducing VF - the maximum safe level. They then compared this value to the standard device discharge and the ratio of the two values, the VF threshold to the standard discharge was defined as the safety index.

The study found that the safety index ranged from 15 to 42 times the standard Taser X-26® energy output as animal weight increased from 30 to 117 kg in a nearly linear fashion. In other words, the study found that the taser discharge required in order to induce VF was 15 to 42 times the energy output of the standard taser discharge. This safety factor increased with the size and weight of the subject. They concluded that discharge levels output by fielded Taser X-26® devices have an extremely low probability of inducing VF. The authors contend that their results suggest it is unlikely that VF or cardiac dysrhythmias are responsible for sudden deaths that have occurred after Taser activations.[28]

An Air Force Research Laboratory animal study by Jauchem et al investigated the metabolic effects of repeated activations of a CED.[29] Sedated pigs weighing 49.5 to 58 kg received five-second discharges alternating with five seconds of rest for three continuous minutes. Animals demonstrated transient, clinically insignificant increases in potassium and sodium, a significant decrease in blood pH that returned toward normal at one hour post exposure, a significant rise in blood lactate that returned to baseline at two hours, and a significant rise in whole blood pCO2 that returned to baseline at one hour. Animals then underwent one hour of monitoring followed by an additional three minutes of the five seconds of CED activation alternating with five seconds of rest. Additionally, the authors followed the levels of Troponin I, a cardiac specific muscle enzyme that is a marker of damage to the heart. While the levels of this enzyme did not approach the predetermined cut off of 0.35ng/ml there were slight rises after the discharges, though not of statistical significance. The conclusions of the authors were that although a 3 minute exposure as outlined above resulted in significant changes in blood chemistries, most levels returned to pre-exposure levels within in one hour after exposure. The applicability of this model to humans has yet to be determined.[29]

Wu et al performed a study aimed to find the distance from the tip of a CED dart to the heart that caused ventricular fibrillation (VF) in repeated attempts.[30] Using ten pigs weighing 53.8 to 74.4 kg, the animals were anesthetized, intubated, and monitored. One dart, they called the "heart dart", was placed over the right ventricle in decreasing distances (from 20cm downward) after skin and muscle were dissected away. This was the distance that the authors measured. The other dart was placed on the abdominal surface, anywhere from 15 to 54 cm away from the "heart dart". Five second CED discharges were used for the simulation. Starting at 20cm the discharge was delivered. If no VF was noted, then the distance was reduced by 2 cm and the discharge repeated. Once they induced VF, they did further experiments to determine the energy for subsequent induction of VF. The dart-to-heart distance that caused VF on the first attempt was 17mm +/- 6.48 (SD) and for the average of subsequent attempts was 13.7 +/- 6.79 (SD). The authors also measured skin to heart distance in healthy human volunteers using echocardiography and found that distance to be 10-57cm in 150 subjects. They then performed a calculation that shows that the probability of the "heart dart" landing in the 1cm^2 that would make a person most susceptible to VF and that person having a skin to heart distance that would make them susceptible to VF as noted by the study to be 0.000187. The conclusions of the study suggest that the conditions necessary for electrocution of the heart are the heart dart landing in the area over the heart suggested by the results which is an extremely low probability event. They also recommend that all law enforcement CED training should be done with probes in the back avoiding the torso.[30]

Lakkireddy et al tested 9 different pacemakers and 7 different internal cardiac defibrillators (ICD) in a swine model after a standard Taser shock.31] The two darts of the Taser X-26 were placed at the sternal notch and the apex of the heart. Though the devices detected and interpreted the Taser discharges as cardiac electrical activity, and in some cases prepared to deliver a corrective shock, none were affected in a negative fashion by the discharges and none actually delivered a shock as the termination of the 5 second Taser discharge aborted any shock delivery by the device.

The study used a single small pig that weighed 28kg and the dart at the apex was 15mm from the heart. The location of darts also bracketed the cardiac devices tested. Each device was tested using 3 standard discharges of 5 seconds each. No episodes of VF or ventricular tachycardia (VT) were initiated by the Taser shocks.

If an individual's ICD was set for a time to shock delivery on detection of these impulses of <5 seconds, it is conceivable that a CED discharge could cause an ICD to deliver a corrective shock. It is also possible that in a pacemaker that is inhibited by the sensing of native electrical activity, that the

CED discharge could inhibit the pacemaker from delivering its needed pacing activity.

The conclusions of the study are that a Taser X-26® discharge does not affect the short term functional integrity of the implantable pacemakers and ICD's tested and that the standard duration discharge of 5 seconds should not result in delivery of an ICD shock in devices programmed to a non-committed shock mode.[31]

As a follow up to prior studies that suggest that pacemakers and ICD's do in fact detect CED discharges and interpret them as native cardiac activity, Calton et al performed a simple, brief study to look at whether or not longer duration CED discharges (>5secs) could result in an ICD delivering a corrective shock.[32] Using two darts, one in the right parasternal region and one in the left lateral border of the thorax; the distance between the darts was 30cm. They used a TaserM-26® to deliver a 5 second and then a 15 second discharge. During the 5 second discharge, the devices detected the activity and charged but did not deliver their corrective shock because the discharge had terminated prior to the time to deliver the shock. However in the 15 second discharge, the ICD did actually deliver 2 separate shocks.

The conclusions of the study were 3 fold- 1) in patients with newer devices longer CED discharges (15secs) could result in ICD discharge, 2) because most devices are committed to deliver a shock after the first VF therapy, an inappropriate shock may be delivered even after the CED discharge is no longer being given, and 3) in older models of devices that only shock after sensing VF, then even a short burst of energy could result in inappropriate ICD shocks.[32]

Nanthakumar et al aimed to evaluate the cardiac consequences of CED use on six anesthetized pigs weighing 45-55kg. They tested both the Taser X-26® and Taser M-26®. They performed experiments with varied location of darts including across the chest or across the abdomen, and varying duration of discharges of 5secs or 15secs. The darts located across the chest were placed one 5cm to the right of the sternum, and the second placed on the left lateral border of the thorax with an inter-dart distance of 26 to 30cm. In a separate arm of the study, the animals were also given an infusion of epinephrine (adrenalin) to simulate physiologic stress.[33]

When the discharges across the chest were recorded, 79% of the time the myocardium was directly stimulated based on their criteria. The Taser X-26® caused capture in 98% of discharges versus the Taser M-26® only 53.6%. Going from 5 to 15 seconds in the Taser X-26® cased a change from 96% capture to 100% capture. In the M-26® the rate went from 47% to 60%. In the simulated stress group, 13 of 16 discharges resulted in VF or VT.

These numbers are very high when compared with other studies on pig models looking at myocardial capture. The model of darts across the heart does assume a "worst case scenario". The authors conclude that Taser discharges across the chest can produce cardiac stimulation at high rates.[33]

Lakkireddy et al in a pig model studied the effects of cocaine on the CED induced VF threshold, which is the amount of energy required to induce ventricular fibrillation. Using five adult pigs weighing 34 +/- 8.7kg, they used a custom device to deliver multiples of the standard Taser discharge from the Taser X-26® in a step up and step down fashion in order to determine the VF threshold. They used 5 different locations of dart placement (3 on the ventral surface, and 2 on the dorsum). The results showed that in a single 5 second discharge, VF was not induced in any dart position. The most sensitive position for VF induction was the sternal notch to PMI (point of maximal impulse, the location on the chest where the heart is felt strongest by placing one's hand over the chest) position on the chest. The infusion of cocaine actually increased the safety margin of the device in a pig model from 1.5 to 2 times from baseline. Plasma levels of cocaine and benzoylecgonine 30 minutes after infusion were reported as 557 +/- 280 U/l and 462 +/-123 U/l respectively.[34]

Review of the Literature: Case Series and Reports

The use of CEDs has been associated with cases of sudden in-custody deaths and has generated controversy in the lay press. Amnesty International (AI) reported in 2004 that more than 70 persons have died after CED activations by law enforcement and described many of those and other non-lethal scenarios in detail. (Amnesty Int website) Their conclusion was that while there is no clear causal link between CED use and adverse outcome, there is a significant need for further research on this subject. The Amnesty International report also concluded that use of electro-shock devices is open to abuse, and recommended that law enforcement agencies strictly limit their use and provide full review and reporting with each deployment.

Kornblum and Reddy examined sixteen deaths that were associated with Taser use during a five year period from 1983-1987.[35] All involved young men with a history of abuse of controlled substances and all but three were under the influence of cocaine, PCP, or amphetamine. Each was behaving in a bizarre or unusual fashion that necessitated a police response. The causes of death were determined to be drug overdose (11), gunshot (3) and undetermined (1). In those cases where the person was not under the influence of drugs, two expired of gunshot wounds and another died after being placed in a chokehold.

There is one case in which these authors felt a Taser may have contributed to a death. The subject had a history of cardiac disease and it had been recommended he receive a permanent pacemaker - though he did not follow up. At autopsy it was determined he had both a diseased heart and lethal levels of PCP. The cause of death was listed as cardiac arrhythmia due to sick sinus syndrome, prolapse of the mitral valve, and electrical (Taser) stimulation while under the influence of PCP. The authors concluded that the Taser by itself did not cause death, but may have contributed to death. The authors suggested that the subjects in this study died after being in an agitated state known as "agitated delirium," what we refer in this report to as excited delirium, with drug intoxication causing or predisposing the subjects to vulnerability to sudden death.[35]

These results were challenged by a pathologist from the Los Angeles Coroners Office. Allen criticized the authors' conclusions suggesting that the Taser was at least partly responsible for 9 of 16 of the deaths. "Obviously if a person is shot with a Taser and then immediately killed with bullets, we are not in a position to draw a conclusion about whether the Tasering was fatal. A similar consideration applies when forceful restraint or chokeholds, which can also result in fatalities, are used. My point is that, with more than one type of injury, we are not free to exclude the Taser potentially contributing to death." [36]

In a prospective case review conducted from 1980 to 1985, investigators studied 218 patients who presented to the emergency department (ED) after being shot with a CED.[59] These patients were compared with 22 similar patients who were shot by police with 0.38 caliber handguns during the same period. Seventy-six percent of all of cases in which the CED was utilized involved subjects displaying bizarre and uncontrollable behavior. Ninety-five percent were men and 86% had a history of recent PCP use.

The mortality rate in the CED group in this study was 1.4% (3 of 218 patients). All three patients who died were in asystole upon arrival to the ED. Taser probes were embedded in the thigh, buttocks and back of these patients. All had high levels of PCP and all went in to cardiac arrest shortly after receiving the CED activation, from 5 to 25 minutes post- deployment. The Medical Examiner reports on these cases listed PCP toxicity as the cause of death and there were no signs of myocardial damage, airway obstruction or other fatal pathologic findings. When compared with the complications and injuries sustained from the 0.38 caliber handgun, the authors concluded that there was a marked and statistically lower rate of mortality and morbidity when the CED was used.[37]

A recent review by Strote and Hutson of 28 autopsy reports available on 71 CED-related deaths retrieved from Lexus-Nexus and Google searches identified no deaths directly from CED use, although 6 (21%) noted that the CED may have been contributory. Excited delirium was thought to be either directly or indirectly related in 57% of the cases.[38]

Another review by Vilke, et al involved the evaluation of 118 unique proximity deaths in subjects who had CED activations. These cases involved a total of 96 law enforcement jurisdictions in 26 different states. Each agency was surveyed, with 60 (63%) agencies responding, resulting in data from 65% (77 of 118) of the CED proximity deaths. The majority of deaths were males (96%), White (46%) and individuals 31-40 years of age (38%). Among the 77 subjects, 20 (26%) were armed at some point during the incident including 4 (20%) with a firearm, 8 (40%) with a knife/cutting weapon and 5 (25%) with a club/baton/blunt force weapon. Undesirable behaviors were also common with 58 (75%) exhibiting non-compliance, 53 (69%) severe aggression and 39 (51%) mild aggression.[39]

In a case reported by Haegeli et at, a 51 year old 75 kg female with an implantable cardioverter- defibrillator (ICD) was exposed to Taser M-26® with a five second activation. The probes were located in the sternum and she had no complications at the time of the activation. Two months later, she had her routine follow up of her ICD with her cardiologist. At that time, they reviewed the recordings on the ICD around the time of the Taser activation. She had sinus tachycardia immediately before activation running about 135-138 heartbeats a minute. During the Taser activation, signals were between 135 and 275 beats, causing the ICD to interpret her rhythm as an irregular heartbeat; ventricular fibrillation. Based on this misinterpretation, the ICD charged to deliver a defibrillatory shock, but did not deliver it to the subject because the Taser activation stopped by the time the device was fully charged. No true cardiac irregular rhythms were ever detected, only artifact from the Taser activation that mimicked VF and caused the ICD to prepare to defibrillate with a shock. The authors concluded that given the generalized tetanic contractions of most of the skeletal muscles during CED energy delivery, there is likely no safe distance for a CED hit in the presence of an ICD. No damage to the circuitry, including pacing functions, or reprogramming of the ICD occurred.[40]

In a letter to the editor, Kim and Franklin reported the case of an adolescent who was subdued with a CED and subsequently collapsed. Paramedics found the adolescent to be in VF on their cardiac monitor and began performing cardiopulmonary resuscitation within two minutes after the collapse. After four shocks and the administration of epinephrine, atropine, and lidocaine, a perfusing cardiac rhythm was restored. The adolescent made a near complete recovery and was discharged from the hospital several days later. The authors conclude that VF can occur after a discharge from a stun gun and suggested that law-enforcement personnel carrying stun guns should consider also carrying automated external defibrillators. As a letter to the editor, a great deal of detail is lacking from this case to determine if the CED had a causative role in this case. For example, there is no commentary on what mode the CED was used during deployment, if the child was taking any drugs, or whether the child had any previous cardiac conditions.[41]

Other case reports include the case of a 27 year old man who had received a CED activation, and then while in the back of the ambulance, pulled out and swallowed the Taser barb so that when the autopsy he anticipated would be performed after he died from the incident was performed "they would know it was the police" that killed him. The patient did not die and did well with no subsequent medical issues. [42] Given the projectile nature of CED darts there have been several other case reports published describing eye injuries as well as bone penetration in a subject's finger.[43-45]

Review of the Literature: Human Physiologic Studies

Physiologic studies in human subjects offer direct insight into the effects of CEDs beyond that of animal studies. However, these studies are often challenging to perform for a variety of reasons, including the reluctance of human volunteers to participate, as well as a hesitance by research protections committees to approve such studies in light various perceptions regarding the safety of these devices. In addition, while a clinical laboratory setting allows the greatest control and measurement of important physiologic parameters, not all conditions that occur in the field setting, such as struggle, drug intoxication, and physiologic or psychological stress, can be reproduced with exact accuracy.

Despite these challenges, there is a growing body of recent literature and research on the physiologic effects of CEDs in human subjects. These studies have been both industry sponsored (primarily by Taser International, Inc.) and non-industry sponsored. Most of this work has been conducted by two research teams – Jeffrey Ho's team out of Minnesota, and a group at the University of California, San Diego (UCSD) which includes the authors of this report. In large measure, the findings from both these research groups are complimentary and the human physiologic studies to date have yet to find evidence of significant deleterious effects of CEDs on human subjects.

Ho's group conducted a study sponsored by Taser International, Inc. investigating the effect of a standard 5 second Taser X-26® discharge on 66 human subject volunteers (65 men and 1 woman, age range 29 -55 years) recruited at a Taser International training course.[46] Prior to the discharge, subjects had blood drawn for markers of heart muscle damage, skeletal muscle damage, electrolyte disturbances and kidney function (troponin, myoglobin, lactate, potassium, glucose, blood urea nitrogen, creatinine, and creatine kinase levels). In addition, 32 of the subjects selected randomly had electrocardiographic evaluation prior to the Taser discharge.

The Taser X-26® device was deployed at 7 feet from the subject with the subject turned away from the weapon. During the 5 second discharge, personnel supported the individual, but would assist them to the ground if they fell. Blood tests were repeated immediately following the discharge and again at 16 and 24 hours. For the group undergoing electrocardiographic monitoring, repeat electrocardiography (ECG) was performed at these times as well.

The investigators reported no evidence of electrolyte disturbance or kidney dysfunction following the Taser discharge. In particular, there was no evidence of elevated potassium levels (hyperkalemia) that might have been associated with cellular injury. There was evidence of skeletal muscle activity with elevated myoglobin (all 3 times after Taser) and lactate (initial post-Taser level elevated, but decreased at 16 and 24 hours). For the ECG subgroup, there were no changes between the pre-Taser and post-Taser ECGs. Two subjects had abnormal ECGs at baseline with no changes following the Taser.

All troponin levels for cardiac injury were normal (<0.3 ng/ml) with the exception of one subject who had a single elevated value (0.6 ng/mL) at the 24 hour post-Taser mark. This subject was evaluated in a hospital by a cardiologist and underwent further testing that demonstrated no evidence of acute myocardial infarction (heart attack) or cardiac injury in treadmill stress testing and heart imaging (rest/adenosine-augmented myocardial perfusion study). According to the authors, this individual was also never symptomatic and continued with his usual activities after hospital evaluation without difficulty. From their results, Ho et al. concluded they were unable to detect any abnormal cardiac rhythms, direct cardiac cellular damage, or evidence of hyperkalemia that may be related to death proximal to CED exposure.[46]

Three other non-industry sponsored studies conducted by the UCSD group also investigated the cardiac effects of CEDs in human subjects and reported results concordant with the findings of Ho's group. Levine et al conducted a prospective, observational study of 105 law enforcement officers undergoing CED training who volunteered to receive a standard Taser X-26® discharge by either projectile probes or alligator-clip attachments.[47] Subjects were monitored by means of a 3-lead electrocardiographic monitor at least 5 seconds before the discharge, during the discharge (average duration 3.0 seconds, range 0.9 to 5.0 seconds), and for at least 5 seconds after the discharge. After excluding 10 subjects because of monitor lead dislodgement during the CED discharge, there were no significant abnormal cardiac rhythms disturbances or electrocardiographic anomalies detected comparing the pre-discharge with the post-discharge monitoring. The only notable finding were that subjects had an elevated heart rate prior to the CED discharge (average 122 beats/minute, range 66 to 175 beats/minute) that significantly increased after the CED discharge (average 137 beats/minute, range 75 to 190 beats/minute). This finding is of unclear clinical significance and likely is related to the pre-shock anxiety many subjects experienced, along with the painful stimulus that occurred with the CED deployment.

In follow-up to this study, Vilke et al. reported on 32 human law enforcement personnel volunteer subjects (27 men, 5 women) who had the more extensive 12-lead electrocardiogram performed immediately before and within 1 minute following a Taser X-26® discharge (average duration 2.1 seconds).[34] The more extensive 12-lead electrocardiogram allowed investigators to measure actual times in the cardiac cycle including the PR interval (time from atrial to ventricular activation), QRS interval (ventricular activation time) and QT intervals (ventricular recovery time), for which any abnormalities could predispose subjects for abnormal cardiac rhythms. The authors reported a minimal increase in heart rate after the Taser discharge (increase of 2.4 beats/minute), and a slight decrease in PR interval, but otherwise no significant changes or abnormalities in QRS or QT intervals that would put an individual at increased risk for an abnormal cardiac rhythm. When stratified by gender or body mass index, the investigators reported no clinically relevant changes in their findings.[48]

The third related study from the UCSD group was reported by Sloane, et. al., who described a prospective cohort study of 66 law enforcement volunteers who underwent a standard Taser X-26® discharge (average duration 4.36 seconds, range 1.2 to 5 seconds) and subsequently had a blood serum troponin level drawn at 6 hours after the discharge.[49] A 6 hour troponin level has been shown to be both sensitive and specific for the detection of myocardial infarction (heart attack) in the clinical setting. The investigators reported that none of the 66 subjects had an elevated troponin level (>0.2 ng/ml), indicating that none had evidence of myocardial necrosis (or injury to the heart cells) as a result of the Taser discharge.

Recent work from Ho's group has focused on the impact of CEDs on respiratory function, particularly focusing on the effect of prolonged CED discharges.[50] Ho et al conducted a prospective observational study in 52 human volunteers who underwent either a continuous 15 second Taser X-26® discharge (34 subjects) or three 5-second repetitive exposures with 1 second intervening intervals (18 subjects). Because of the continuous or repetitive exposure, subjects were placed in the supine position on a mat with manually placed Taser electrodes on the trunk or leg. Subjects underwent respiratory and ventilatory monitoring and data collected included oxygen and carbon dioxide (CO2) concentration measurements of expired air, respiratory rate, and tidal volume on a breath-by-breath analysis. Monitoring of these parameters occurred at baseline prior to Taser discharge, during the actual continuous or repetitive discharge, and after the Taser discharge until the subjects measurements returned to baseline.

The investigators reported that measures of ventilation actually increased during the Taser discharge in both the continuous and repetitive discharge groups indicating that subjects were not only able to breath, but actually increased their ventilatory and breathing efforts during the Taser activation. In the continuous discharge group, average minute ventilation (liters/minute or l/min) increased from a baseline of 16.3 l/min to 20.9 l/min, average respiratory rate increased from 15.9 breaths/min to 18.3 breaths/min, and average tidal volume (volume of air for each breath) increased from 1.1 L to 1.8 L. A similar, though smaller trend was seen with in the repetitive group with increases in minute ventilation (17.5 to 19.5 L/min), respiratory rate (14.6 to 18.7 breaths/min), and tidal volume (1.4 to 1.5 L) from baseline to during the Taser activation period.

In addition, the investigators reported that there was both an increase in oxygenation and decrease on CO2 concentrations in expired air, all consistent with evidence of increased breathing and hyperventilation during the Taser activation. For the continuous discharge group, mean oxygen concentration increased from 118.7 mmHg to 121.3 mmHg, and mean CO2 concentrations fell from 40.5 mmHg to 37.3 mmHg from baseline to the Taser activation period. For the repetitive discharge group, mean oxygen concentrations increased from 123.1 mmHg to 127.1 mmHg, and mean CO2 concentrations fell from 40.9 mmHg to 39.1 mmHg. Based on their findings, the authors concluded that they were unable to detect any respiratory impairment, and indeed detected just the opposite with increased ventilation during either a prolonged continuous or intermittent CED activation. They found no evidence of decreased ventilation, increased CO2 retention, decreased oxygen levels, or apnea (cessation of breathing) during the prolonged Taser activation.

The UCSD group has recently conducted a comprehensive prospective trial funded by the US Department of Justice investigating the effects of a standard 5 second Taser X-26® discharge on 32 healthy law enforcement personnel (27 men and 5 women) who were undergoing training on the device and volunteered to receive a Taser activation.[51] Subjects were monitored in terms of their cardiovascular, respiratory and metabolic physiology to determine the effect of the CED discharge. Cardiovascular measurements included 12 lead ECG at baseline and 1 hour post-activation, Troponin I levels at 6 hours post activation, and vital signs including heart rate and blood pressure measured at baseline and serially every 5 or 10 minutes following the discharge. Respiratory measurements included minute ventilation, tidal volume, respiratory rate, end tidal pCO2, measured at baseline and during the first 5 minutes after the Taser discharge, as well as subsequently at 10, 30 and 60 minutes. Pulse oximetry was measured for oxygen saturation at baseline and serially similar to the vital signs measurements noted above. In addition, arterialized capillary blood was drawn for pH (acid/base status), pO2 and pCO2 concentrations at baseline, 1, 10, 30 and 60 minutes after Taser discharge. Metabolic measurements included blood sampling for electrolyte levels (calcium, sodium, potassium, bicarbonate) and lactate levels at baseline, 1, 10, 30 and 60 minutes after Taser discharge.

Vilke et al reported the results of this comprehensive study.[51] In terms of cardiovascular physiology, there was no evidence of ischemia or interval abnormalities noted on the 12-lead ECG before or after Taser discharge. All 6 hour troponin levels were normal in the subject population. There were no significant differences in heart rate or diastolic blood pressure before or after the Taser discharge. There was a statistically significant decrease in systolic blood pressure from baseline to 60 minutes following the Taser activation (mean 139 mmHg to 123 mmHg), but no evidence of hypotension or clinically significant abnormal vital signs.

In terms of respiratory function, minute ventilation, tidal volume and respiratory rate all increased from baseline to the first minute following Taser activation indicating an increase in ventilation during this time (mean increase of 12.8 L/min in minute ventilation, 0.5 L/breath in tidal volume, and 3.8 breaths/min in respiratory rate). In terms of oxygenation, there was no evidence of abnormally low oxygen levels (hypoxia) throughout the monitoring period by pulse oximetry measurement of oxygen saturation. There was also no evidence of hypoventilation or retention of CO2 in arterialized pCO2 concentration or etCO2 measurements.

In terms of metabolic physiology, there were statistically significant changes in pH, bicarbonate and lactate levels initially following the Taser discharge, which returned to baseline levels within 30 to 60 minutes. Acid/base status or pH decreased significant at 1 minute (mean change -0.02), but returned to normal at 10 minutes. There was no evidence, however, of an abnormal increase in blood acidosis as mean pH levels were above 7.4 at all time periods. Bicarbonate levels, which often mirror pH and acid/base status also were lower at 1 and 10 minutes (-1.2 and -1.8 mEg/L, respectively), but returned to baseline levels at 30 minutes. Lactate levels increased a small amount at 1 and 10 minutes (1.3 mmol/L and 1.0 mmol/L, respectively), but also returned to baseline levels at the 30 minute measurement. Otherwise, there were no significant abnormalities or differences in the other electrolyte measurements including potassium levels. The investigators concluded from this study that in healthy individuals, a 5 second Taser X-26® discharge did not result in any clinically significant changes in cardiovascular function, respiratory or ventilatory parameters, or metabolic physiology other than transient changes in lactate and bicarbonate levels, with no evidence of acidosis.

While the work of the Ho and the UCSD group studies have shown that CEDs have little risk of detrimental physiologic impact on healthy subjects in controlled clinical investigations, the effect of CEDs in combination with other factors, such as subject exertion, intoxication and stress, commonly encountered in the field setting, have yet to be determined. To that end, recent preliminary research has attempted to address these questions.

The Ho group recently presented data on the effect of CEDs in acidotic subjects following exertion.[52] In this industry-supported study, 44 human volunteers underwent an anaerobic exercise regimen, of whom 38 received a CED discharge and 8 received a sham exposure. The investigators reported no differences between those who received the actual versus sham CED discharge in terms of pCO2 change, oxygenation change, lactate increase or troponin levels. They concluded that markers of acidosis and cardiac injury were similar among acidotic subjects who underwent both real and sham CED exposures following exercise.

This same group of investigators also recently presented data on the effect of prolonged CEDs (15 second exposures from a Taser X-26®) on 25 human volunteers following a exercise regimen of timed push-ups and elevated treadmill sprint until subjective exhaustion designed to simulate the physical exertion seen in subjects in the field.[53] Twelve-lead ECGs were obtained at baseline and following the Taser discharge. All post-Taser ECGs were interpreted as normal with no evidence of dysrhthmias or cardiac injury.

The UCSD group will be presenting preliminary data on a prospective, controlled trial comparing cardiac, respiratory and metabolic physiologic parameters in subjects after exertion alone and following a Taser X-26® discharge.[54] Initial results indicate that systolic blood pressure decreased linearly from a slightly elevated baseline prior to Taser (140.9 mmHg at baseline) to normal (124.8 mmHg at 60 minutes) (decrease=16.1, 95% CI=8.3, 23.9, p=0.002). Heart rate decreased linearly post exercise through the observation period. Oxygen saturation never dropped below 96% for any specific measure interval. pH and bicarbonate levels both decreased from baseline to post exercise (pH decrease =0.12, 95% CI 0.08, 0.16; bicarbonate decrease=4.1, 95% CI 2.7, 5.6) while lactate increased (increase=6.4, 95% CI 4.8, 8.0). pH and lactate did not change from post exercise compared to 1-min and 10-min post TASER (p's > 0.05). Bicarbonate measures were lower at 1-min and 10-min post TASER when compared to post exercise (decrease=3.8, 95% CI 2.1, 5.5 at 1-min and decrease=2.9, 95% CI 0.6, 5.2 at 10-min) before starting to increase toward baseline measures at 30-minutes post TASER. The pH returned to baselines levels by 30-min post TASER (p>0.05) and bicarbonate and lactate returned to baseline levels by 60-min post taser (p>0.05). No changes were clinically significant. The conclusions were that there were no clinically significant or lasting statistically significant changes in selected blood measures or cardiovascular levels in exercised human subjects after rigorous exercise and a 5 second Taser activation.[54]

Recently, the Ho group presented data examining the effect of CEDs on intoxicated subjects.[55] In this remarkable industry-sponsored study, 26 human volunteers were given mixed drinks in a controlled setting to achieve a blood alcohol level of 0.08 mg/dl, after which 22 of the subjects received a 15 second CED discharge (4 subjects served as controls). Compared with controls, the CED group demonstrated a transient increase in lactate and small drop in pH that corrected within 24 hours. There were no changes in markers of cardiac injury and no evidence of elevated troponin levels in either group.[55]

Physiologic Effects of CEDs on the Human Body

The following sections on the physiologic effects of CEDs refer to those devices with probe spread wide enough to cause muscles tetany and incapacitation, as well as pain. Such CEDs cause electro-physical involuntary contraction of skeletal muscles and override the nervous system, resulting in loss of motor control by the subject. This incapacitation occurs regardless of the subject's mental focus, training, size or state of drug intoxication.

During activation of the CED, the subject is more often than not unable to voluntarily perform any motor task, yet remains conscious with full recall of the event. After the electrical discharged is halted, the subject is immediately able to perform at their cognitive and physical baseline, though some report mild fatigue and muscular soreness afterwards.

The effects of CEDs vary depending on the type of device being used, location, placement and distance between the probes on the subject's body as well as the physical condition of the subject. If the probe spread on the body is less than 5 cm, there will be a lower degree of effectiveness than if the probes are spaced more widely apart, allowing the electrical discharge to affect a larger portion of the subject's musculature.[56] The effectiveness of CEDs has been anecdotally reported to increase with the duration of application, in that prolonged activation may result in muscle fatigue after the discharge is halted.[57]

Published medical research on the health effects and safety of CEDs in humans has been very limited and, until recently, most physiologic investigations have been conducted in animal models. There have been a number of editorials, letters to the editor, and review papers, but these are not true scientific studies and really do not offer much to the knowledge base of the medical effects of Tasers, rather opinion and conjecture.[56-69] The governmental regulatory approval of the original CED devices was not based on either human or animal studies, but "theoretical calculations of the physical effects of dampened sinusoidal pulses", from which the U.S. Consumer Product Safety Commission concluded that the Taser should not be lethal to a normal healthy person.[69] Understanding of the anatomic and physiologic effects of CEDs is critical to understanding their safety.

Muscular Effects

As previously described, CEDs create intense involuntary contractions of skeletal muscle causing the subject to lose the ability to directly control the actions of voluntary muscles. This incapacitation is due to an electrical effect and stops as soon as the electrical discharge is halted. Residual muscle soreness is occasionally reported but there are no known permanent effects on the muscular system beyond injuries that may result from an associated fall. It is possible that extensive muscle activity, as a result of agitation, struggle or heavy exertion, along with the effect of a CED discharge on the muscles could potentially increase a risk of rhabdomyolysis, which is muscle tissue breakdown that can lead to kidney failure and other complications. However, the contribution of a CED on the development of rhabdomyolysis is likely minimal when only a few shocks are administered.

Skin Effects

CEDs will often leave a mark at the site of probe contact. These so called "signature marks" are of little medical consequence unless they hit in area of vital concern such as the face, eye, genitalia, or breast. These marks are in addition to the small puncture wounds that occur from the barbs penetration of the skin. Unless they occur in an area of anatomic concern near sensitive structures, there is little residual effect. Attention must be paid to underlying structures, as the barbs have the potential to cause penetrating injury as with any minor puncture wound. The only published work in the medical literature on human cutaneous effects of CEDs was by Anders et al who described on autopsy the histological changes of a 61 year old male who was tortured with a stun gun during a robbery.[70]

Skeletal Effects

CEDs have not been shown to have any direct effect on the human skeletal system. However, injuries such as arm and shoulder injuries as well as facial trauma have been reported as a result of falls of subjects from a standing height from CED applications. There have also been reported cases of vertebral compression fractures in volunteer subjects undergoing a CED shock application. The proposed mechanism for these spinal fractures is related to the location of the barb contact points on the back of the subject across the relatively large paraspinous muscle groups. Forceful contraction of these large muscle groups of the torso can result in enough force to cause an acute compression fracture of the vertebral body. This is similar to the proposed mechanisms for compression fractures that have been reported after seizures.[71-73]

Brain and Central Nervous System Effects

There are no reported adverse effects by the CED on the central nervous system. Subjects who have had CED activations remain awake and alert during the exposure and resume normal central nervous system function and control afterwards. In addition, subjects have full recall before, during and after the event. There is a very noxious pain associated with CED activation, and some individuals have reported residual tingling at the site of attachment of the barbs following the activation. There have been reports of CED probes penetrating through the skull, but no reported direct damage to the brain either by the probe or the associated electrical discharge. There have been no published reports of seizures induced by the use of CEDs.

Psychological Effects

There are no studies on humans evaluating the effect of CED activations on the psychological or emotional state of an individual. There have not been any case reports published in the medical literature reporting permanent psychological or emotional changes from CED use.

Cardiac Effects

In order to understand potential cardiac effects of CEDs, it is important to begin first with a little background. Electrical current applied to the heart can alter the electro-mechanical function of the heart muscle. As a result, devices such as defibrillators and pacemakers, have been designed to direct electrical current to the heart for therapeutic purposes. Pacemakers direct an electrical impulse to the heart at a determined regular rate to help control the rate in an individual whose native rhythm generating ability is not working correctly. The problems with these individuals typically are that the heart rate is too slow because the native electrical pacemaker of the heart is not functioning normally. The implanted pacemaker corrects for this problem.

Defibrillators apply electrical energy to the heart to "reset" the cardiac electrical activity. In essence, these devices put the heart into an asystolic state (no electrical rhythm for the heart) temporarily to allow the native heart electrical pacemaker to resume normal functioning. There are two different types of defibrillators, internal and external. Internal defibrillators are implanted into a patient's chest wall with a surgical procedure and have electrodes that connect directly into the heart muscle. These devices are typically for individuals who have had or are at risk for life-threatening irregular heartbeats. The defibrillator is designed to detect the irregular heartbeat, charge up an electrical defibrillation shock, reconfirm the irregular heartbeat and then deliver the shock if indicated to "reset" the heart's own native electrical activity. External defibrillators are the kind with pads that are placed onto the chest wall that are used by paramedics and emergency physicians to shock an unconscious patient in a life-threatening heart rhythm. Since the energy from external defibrillators must travel through the chest wall, including muscles, bone and fat to reach the heart muscle, the energy of external defibrillators is much greater than internal defibrillators.

Alternatively, electrical current applied to the heart can also cause abnormal electrical activity including life-threatening dysrhythmias such as ventricular fibrillation, (a chaotic, disorganized heart rhythm) and sustained asystole (no heart rhythm). This is the case with electrocution or lightning strikes.

For externally applied currents in humans, induction of ventricular fibrillation (VF) is believed to be a function of the duration, frequency-and magnitude of the current, as well as the subject's own body weight.[68] For an externally applied 60 Hertz (Hz) frequency electrical output, the threshold current for inducing VF in men has been proposed to be 500 milliamps (mA) for shocks of less than 200 ms duration, and 50 mA for shocks of more than two seconds.[68] The longer a current flows, the greater the chance a shock will occur during the early electrical recovery of the ventricles of the heart after contraction (ventricular repolarization), which is known as the electrically vulnerable part of the heart beat or cardiac cycle. Ventricular repolarization constitutes the initial component of the T-wave on the electrocardiogram and lasts for 10-20% of the cardiac cycle.[74] The Taser X26® reports a current of 2.1 mA lasting 0.0004 seconds.[1]

Resistance determines how much current flows for a given voltage (Voltage = Current x Resistance). The lower the resistance, the larger the current and the more likely VF may be induced. The total resistance of the body is the sum of internal resistance plus twice the skin resistance, as current both enters and exits the body [74]. CEDs use very high frequency electricity, and when combined with associated changes in skin resistance these electrical currents tend to stay near the surface of the conductor. Hence, the output of the CEDs is theorized to stay near the skin and muscle surface of the body rather than reaching internal organs such as the heart.[75]

Published studies evaluating the effect of CEDs on cardiac physiology are limited; though in the last 2 years there have been several that begin to address this topic. A porcine study published in 1989 used an older model stun gun that produced high voltages (>100,000 volts) and short duration pulses (<20 microseconds). The investigators compared five different models of stun gun with varying energies. The average value of the current applied during each shock was calculated to be 3.8 mA. When towels were placed between the skin and the electrodes to simulate clothing, the maximum current spike was 190 mA with a pulse length of 20 microseconds. Using two anesthetized normal healthy pigs, the investigators were able to induce VF when the leads of the stun gun were applied directly to the heart or to the chest of one of the animals in which a cardiac pacemaker had been implanted. Importantly, these adverse effects were immediate, not delayed. The authors surmised that the mechanism of action inciting VF was not pacemaker inhibition, but rather fibrillatory current directly accessing the heart via the pacemaker leads. This device's shock also produced cardiac standstill when applied through layers of simulated clothing over a prolonged period. However, these findings only occurred with the two stun gun models delivering the highest energy. There were no cardiac effects seen with the lower energy units.[26] This study demonstrated that VF was indeed possible, but only at very high-energy outputs and when the electrical discharge occurred directly over (or had direct access to) the heart.

In another animal study, the cardiac safety of the devices was tested on nine pigs weighing 60 kg +/-28 kg. The animals were shocked using a device that was developed to be capable of delivering a shock identical in waveform and charge to that of the currently available Taser X26® device. However, the voltage used for this study was less than the 50,000 volts used in the commercial device. The animals were shocked for five seconds with electrodes attached across the thorax of the animals. The study used gradually increasing amounts of delivered charge to identify two threshold levels. The first goal was to determine the lowest amount of charge required to induce VF at least once, defined as the VF threshold. The second goal was to determine the highest activation that could be applied five times without inducing VF, defined as the maximum safe level. The authors then compared this value to the standard device activation and defined the ratio of the two values (the VF threshold to the standard activation) as the safety index. The study found that the safety index ranged from 15 to 42 times the standard CED energy output as animal weight increased from 30 to 117 kg in a nearly linear fashion. Thus, the CED activation required to induce VF was 15 to 42 times the energy output of the standard CED activation. The authors concluded that activation output by Taser devices has an extremely low probability of inducing VF. [28] The authors contend that these results suggest it is unlikely that the use of CEDs caused VF or cardiac dysrhythmias in cases of sudden death in proximity to CED activation.

Recently, Levine et al conducted a study electrocardiographically monitoring 105 human volunteers immediately before and after Taser shock during police training sessions. While mean heart rate increased by 15 beats per minute following the Taser shock, the investigators reported no change in cardiac rhythm or electrocardiographic intervals.[47]

A study by Sloane, et al. assessed for cardiac muscle cell damage after a single 5 second shock. Utilizing a blood assay that checks for the presence of Troponin, an enzyme released within 6 hours after an injury to heart muscle cells, they found that in 66 healthy volunteers, none had an elevation of that enzyme. This suggests that there is no damage to cardiac muscle cells after a single shock. [49]

Respiratory Effects

The mechanics of breathing rely on the muscles of the diaphragm and chest wall to expand the chest cavity and the lungs on inspiration. There has been concern raised that a CED activation could effect these respiratory muscles, particular the diaphragm, and result in inadequate respiration. In theory, this type of hypoventilation could result in lower blood oxygen levels (hypoxia), higher blood carbon dioxide levels (hypercapnea) and increased blood acid levels (acidosis, from the increase in carbon dioxide). Concern has been raised that this respiratory acidosis could develop due to inhibition of respiratory function by repeated or prolonged CED activations. This effect could exacerbate any underlying metabolic acidosis from heavy exertion, drug use or agitation associated with excited delirium. This could potentially precipitate cardiac irritability or abnormal heart function. Studies evaluating humans have demonstrated that people do breathe during CED activations.[50, 51] In one study, the investigators reported that measures of ventilation actually increased during a prolonged fifteen second CED discharge indicating that subjects were not only able to breathe, but actually increased their ventilatory and breathing efforts during the Taser activation.[50]

Other Physiologic Effects

Cardiac Defibrillators and Pacemakers

The effects of CED's on an AICD or cardiac pacemaker have been previously discussed in the previous sections. In summary, it appears that there is animal data to support the assertion that an AICD may detect the CED delivery and interpret it as a cardiac dysrhythmia. If it does that, it is conceivable that the device could deliver an unnecessary discharge to the subject if the CED is used for longer than 5 seconds depending on the particular device [31, 32]. It does not appear that the CED activation is likely to have any adverse effect on the functional integrity of the devices after the activation. Recall, that in the case report by Haegli, the device tested normally at follow up later, but did in fact, charge in anticipation of delivering a shock [40] As postulated based on the animal data, her device did not deliver the shock as the CED activation had terminated in time.

Pregnancy

The safety of CED use in pregnancy is unknown but anecdotal reports suggest its use should be restricted in this circumstance, if possible. A 32-year old woman at approximately 8 to 10 weeks pregnancy received a single three to ten second CED activation, with one probe lodged in the abdomen above the uterus and the other in the left thigh. She fell to the ground and was reportedly unable to move for five minutes afterwards. One day later she began having vaginal spotting that continued for seven days, at which time she was diagnosed with an incomplete miscarriage. Pathologic analysis of the tissue from a uterine curettage revealed products of conception with extensive hemorrhage, necrosis, and inflammation. Though a temporal relationship was suggested between the CED activation and the miscarriage, no causation was established.[76] Another CED use in a six-month pregnant woman resulted in a civil settlement of a damages claim, after fetal demise was diagnosed approximately 12 hours following CED use. No causation was established for the CED in this case as well, which was complicated by a fall following CED activation and by a past history of methamphetamine use.

Children and Elderly

There have been no human or animal studies to evaluate CED safety in the elderly or in children. There is a single case report of a seven month old infant who died after repeated shocks with a stun gun in an abuse case and a letter to the editor of adolescent who went into VF after a CED activation.[41, 77]

Subjects under the influence of drugs and alcohol

There have been no human studies on the effects of CEDs in persons under the influence of illicit drugs. There is a single study of the effect of a 15 second on human volunteers were given mixed drinks in a controlled setting to achieve a blood alcohol level of 0.08 mg/dl. Compared with controls that did not have any alcohol, the Taser group demonstrated a transient increase in lactate and small drop in pH that corrected within 24 hours. There were no changes in markers of cardiac injury and no evidence of elevated troponin levels in either group.[55] In an animal study utilizing a swine model, researchers noted that the infusion of cocaine into pigs actually resulted in a greater amount of energy (1.5 to 2 times as much) being required to cause the heart to be shocked into VF when compared to pigs without cocaine.[33]

Summary Recommendations

Agency Specific Approach to Each Tasered subject

Recommendations presented by the Police Executive Research Forum policy and training guidelines for consideration in October 2005 state that "all persons who have been exposed to a CED activation should receive a medical evaluation." Options and considerations for this medical evaluation are briefly reviewed here.

In the case of a subject who had a CED activation and 1.) becomes compliant, is alert and acting appropriately, and 2.) had the CED darts impact non-medically sensitive areas, many law enforcement agencies have policies and procedures to allow police officers to remove the darts. This seems reasonable if the officer has been specifically trained in the dart removal, utilizes universal precautions as the darts are considered a biohazard, and the dart is not located in a medically sensitive area, typically considered as the face, neck, female breast tissue, groin, hand or genitalia. The subject should still obtain a medical evaluation that would include local wound care and updating tetanus status, however, this could potentially be performed by medical staff at a detention facility or by field paramedics. This practice will vary from jurisdiction to jurisdiction.

For logistical, training, or medico-legal reasons, some law enforcement agencies have opted not to train their officers to remove the CED darts. In these subjects, medical clearance by a physician with removal of the dart is often required prior to the subject being accepted for booking at the jail. The transport of the subject to the local emergency department (ED) by police for medical clearance can result in a long wait for the subject to be seen as a patient. There are often extensive numbers of patients in the waiting rooms and the CED patients may get triaged as lower level acuities, thus resulting in them being placed further down into the queue to be seen by the physician. These delays often result in the frustration of the accompanying police officers as the delay keeps them off the streets. ACT, or Accelerated Care at Triage is a novel approach created by a collaboration between the San Diego Police Department and the University of California, San Diego (UCSD) Medical Center.

ACT is a program implemented at the UCSD Medical Center Emergency Department to facilitate the evaluation and rapid disposition of the subject who received a CED activation and has no other obvious medical issues. The ACT algorithm is demonstrated in figure 1 below.

The ACT program has been successful in getting the low risk compliant and controlled patient quickly discharged from the emergency department and the police officer back onto the streets. Additionally, it has offered the opportunity for earlier evaluation and initiation of therapy for patients brought in by police who are still agitated and combative, and thus at higher risk for morbidity and mortality. This is exactly the population of patient that needs rapid evaluation and treatment. The other unanticipated, but positive effect of the ACT program is that it has improved relations between police officers and medical staff, as both groups feel that optimum care for these patients is delivered in an appropriate timeframe.

Specific Conditions

Taser Probe in Sensitive Area

A taser dart that strikes a subject in a sensitive area of the body, such as face, neck, genitalia, hand, or female breast tissue may present a problem. For that issue, we recommend that removal be performed by a trained medical professional.

Excited Delirium

By virtue of their combative, hallucinatory and non-compliant presentations, many subjects using illicit drugs or having untreated psychiatric illness will undergo CED activation in order to be taken into custody. These subjects are at risk to develop or are excited delirium as previously described. Law enforcement officers should recognize that subjects presenting with this syndrome, or those with a history of cocaine, methamphetamine or PCP use or an untreated psychiatric illness, are possibly suffering from excited delirium. The importance of suspecting excited delirium, with or without CED activation, is that these persons need rapid medical evaluation and treatments, starting with accessing EMS for transport as these patients are at increased risk for sudden death syndrome. Treat them all as medical emergencies. Consideration should be given to calling for EMS prior to CED activation whenever possible in this population of subjects.

Cardiac Implantable Pacemakers and Defibrillators

Given that the issue of whether or not a Taser discharge may actually damage one of these devices is not totally answered, and though this is a low likelihood event, we would recommend that anyone with one of these devices who underwent a CED activation should receive a medical evaluation at a medical facility. These patients usually have an underlying structural heart disease or other reason that resulted in the placement of the device, placing them at higher risk from resultant complication, and therefore warrant extra caution.

Elderly

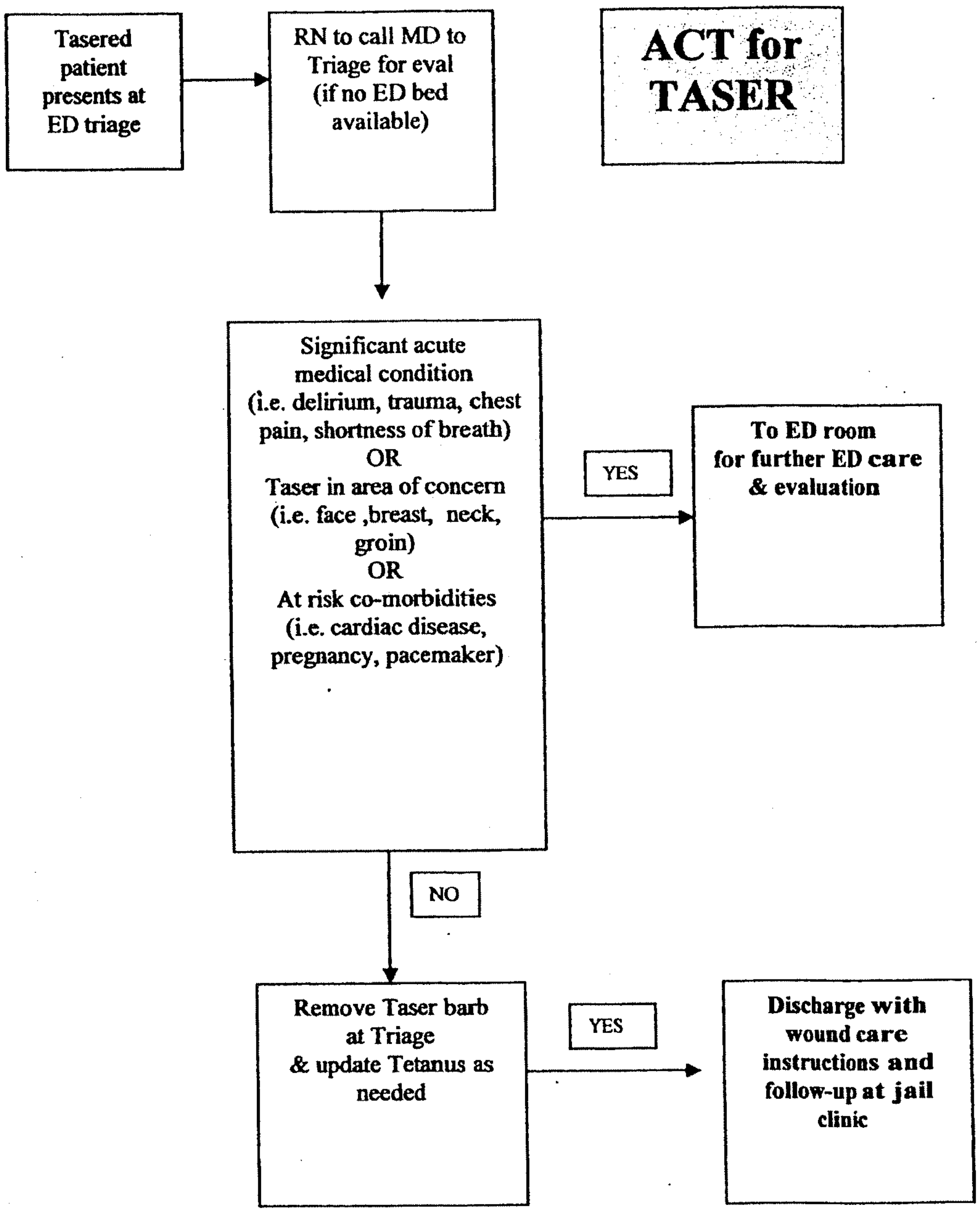
The elderly, by virtue of their more prevalent likelihood of certain diseases, importantly cardiac disease and osteoporosis whether or not silent or previously diagnosed, warrant certain caution. Though it would be difficult to set a defined age cut off, realizing that the likelihood of potential complications rises as does age, a medical evaluation seems prudent.

Children

As there are no controlled trials or experiments using the devices in children, and given their small size and body mass, a medical evaluation is recommended.

Pregnancy

There is no clear consensus as to whether or not CED's represent a threat to the unborn fetus. The case reports described in the prior report do not add much to our ability to clarify this further. Therefore, we would recommend that any pregnant woman, or suspected pregnant woman, be taken to a medical facility with the capability for fetal monitoring prior to incarceration.



ACCELERATED CARE AT TRIAGE

Figure 1

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Definitions-

Asystole- a heart rhythm where electrical activity has ceased, resulting in a lack of contraction of the heart and loss of pulse. Fatal if left untreated.

Autonomic dysregulation- loss of control of the autonomic nervous system that is responsible for control of things one normally doesn't have to think about, breathing, blood pressure, sweating, digestion, etc....

Cardiac Pacemaker- an electrical device for stimulating or steadying the heartbeat or reestablishing the rhythm of an arrested heart -- called also *pacer*

Dysrhythmias- abnormal heart rhythms

Internal cardiac defibrillators (ICD)- a device placed in the body that uses electricity to correct an abnormal heart rhythm.

Myocardial- related to the heart muscle, myocardium

PMI-point of maximal impulse

Rhabdomyolysis- the destruction or degeneration of skeletal muscle tissue (as from traumatic injury, excessive exertion, or stroke) that is accompanied by the release of muscle cell contents into the bloodstream resulting in shock, high potassium, and sometimes acute renal failure.

Sinus tachycardia- abnormally rapid coordinated heart beat.

Troponin I- an enzyme that is released into the blood by heart muscle if damaged. It is normally not detectable in the blood.

Ventricular fibrillation (VF)- very rapid uncoordinated fluttering contractions of the ventricles of the heart resulting in loss of synchronization between heartbeat and pulse beat. Fatal if left untreated.

Ventricular tachycardia (VT)- tachycardia that is associated with the generation of electrical impulses within the ventricles and is characterized by an electrocardiogram having a broad QRS complex. It can be fatal if left untreated.